Atomic Energy

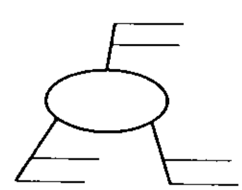
About the PHOTO

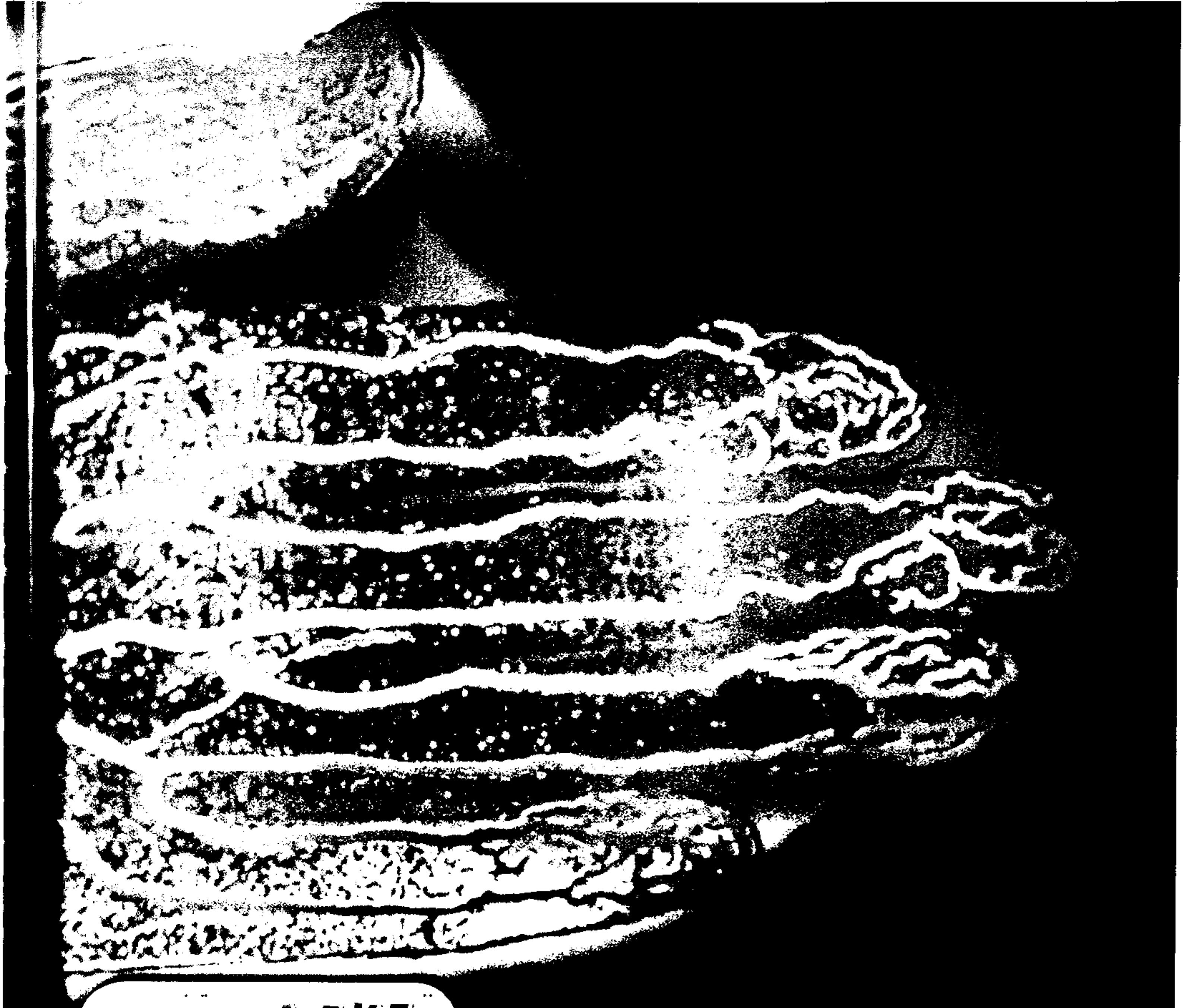
Look closely at the blood vessels that show up clearly in this image of a human hand. Doctors sometimes inject radioactive substances into a patient's body to help locate tumors and measure the activity of certain organs. Radioactive emissions from the substances are measured using a scanning device. Then, computers turn the data into an image.

PRE-READING ACTIVITY

Graphic Organizer

Spider Map Before you read the chapter, create the graphic organizer entitled "Spider Map" described in the Study Skills section of the Appendix. Label the circle "Radioactive Decay." Create a leg for each type of radioactive decay. As you read the chapter, fill in the map with details about each type of decay.





START-UP ACTIVITY

Watch Your Headsium!

In this activity, you will model the decay of unstable nuclei into stable nuclei.

Procedure

1. Place **100 pennies** with the heads' side up in a **box with a lid.** The pennies represent radioactive nuclei. Record 100 "headsium" nuclei as "Trial 0."
2. Close the box. Shake it up and down for 5 s.
3. Open the box. Remove the stable tails-up nuclei, or "tailsium" nuclei. Count the number of headsium nuclei remaining, and record it as "Trial 1."
4. Perform trials until you don't have any more pennies in the box or until you have finished five trials. Record your results.

Analysis

1. On a piece of **graph paper,** graph your data by plotting "Number of headsium nuclei" on the *y*-axis and "Trial number" on the *x*-axis. What trend do you see in the number of headsium nuclei?
2. Compare your graph with the graphs made by the other students in your class.

1

Radioactivity

When scientists do experiments, they don't always find what they expect to find.

READING WARM-UP

Objectives

- Describe how radioactivity was discovered.
- Compare alpha, beta, and gamma decay.
- Describe the penetrating power of the three kinds of nuclear radiation.
- Calculate ages of objects using half-life.
- Identify uses of radioactive materials.

Terms to Learn

radioactivity	isotope
mass number	half-life

READING STRATEGY

Reading Organizer As you read this section, create an outline of the section. Use the headings from the section in your outline.

In 1896, a French scientist named Henri Becquerel found much more than he expected. He found a new area of science.

Discovering Radioactivity

Becquerel's hypothesis was that fluorescent minerals give off X rays. (*Fluorescent* materials glow when light shines on them.) To test his idea, he put a fluorescent mineral on top of a photographic plate wrapped in paper. After putting his setup in bright sunlight, he developed the plate and saw the strong image of the mineral he expected, as shown in **Figure 1.**

An Unexpected Result

Becquerel tried to do the experiment again, but the weather was cloudy. So, he put his materials in a drawer. He developed the plate anyway a few days later. He was shocked to see a strong image. Even without light, the mineral gave off energy. The energy passed through the paper and made an image on the plate. After more tests, Becquerel concluded that this energy comes from uranium, an element in the mineral.

Naming the Unexpected

This energy is called *nuclear radiation,* high-energy particles and rays that are emitted by the nuclei of some atoms. Marie Curie, a scientist working with Becquerel, named the process by which some nuclei give off nuclear radiation. She named the process **radioactivity,** which is also called *radioactive decay.*

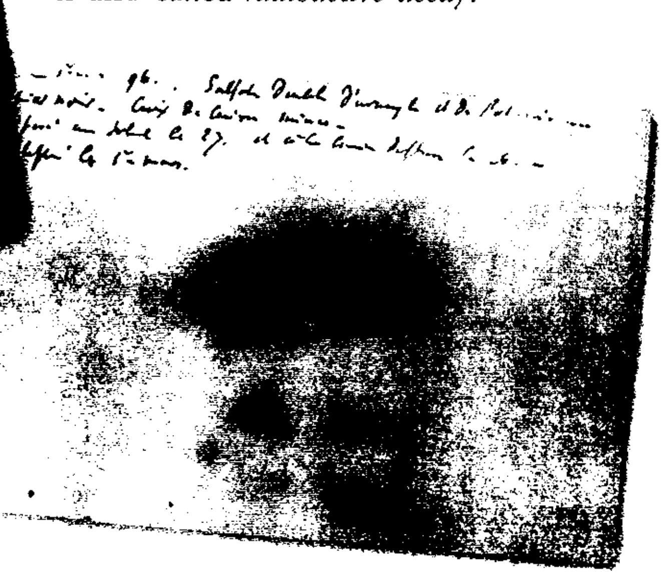
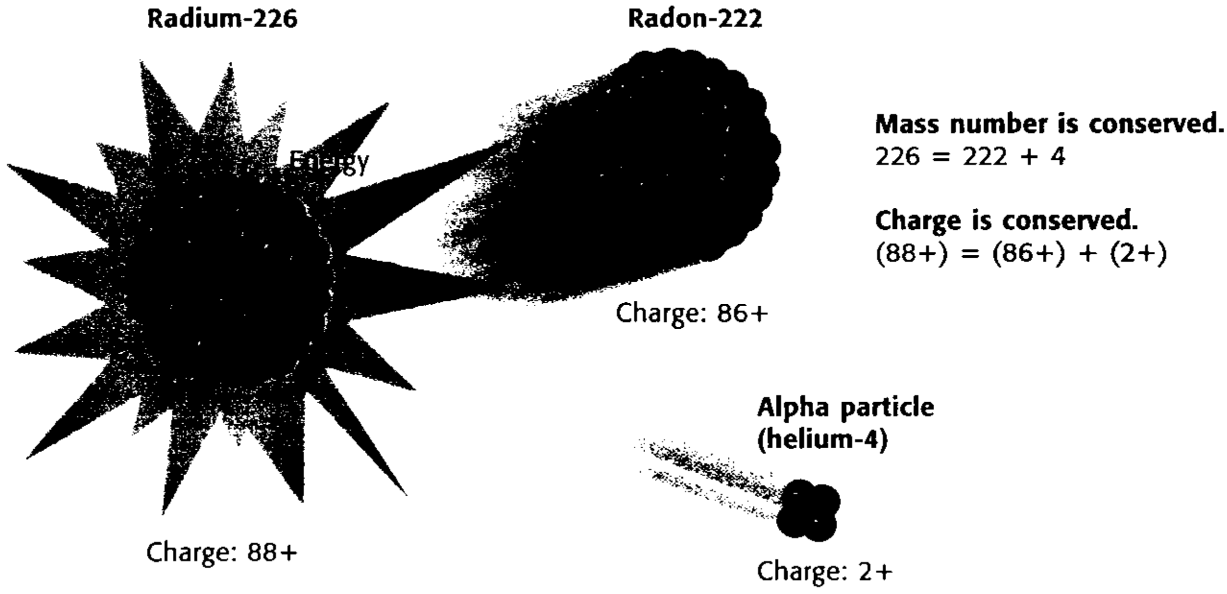


Figure 1 *Sunlight could not pass through the paper. So, the image on the plate must have been made by energy given off by the mineral.*

Figure 2 **Alpha Decay of Radium-226**



Kinds of Radioactive Decay

During *radioactive decay,* an unstable nucleus gives off particles and energy. Three kinds of radioactive decay are alpha decay, beta decay, and gamma decay.

Alpha Decay

The release of an alpha particle from a nucleus is called *alpha decay.* An *alpha particle* is made up of two protons and two neutrons. It has a mass number of 4 and a charge of 2+. The **mass number** is the sum of the numbers of protons and neutrons in the nucleus of an atom. An alpha particle is the same as the nucleus of a helium atom. Many large radioactive nuclei give off alpha particles and become nuclei of atoms of different elements. One example of a nucleus that gives off alpha particles is radium-226. (The number that follows the name of an element is the mass number of the atom.)

[redacted] the process by which an unstable nucleus gives off nuclear radiation

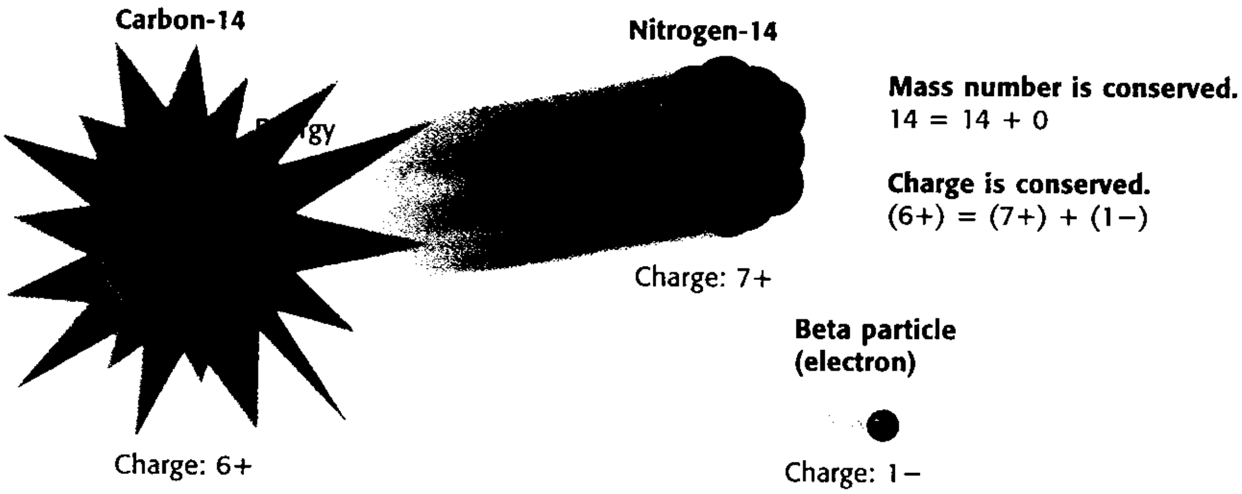
[redacted] the sum of the numbers of protons and neutrons in the nucleus of an atom

Conservation in Decay

Look at the model of alpha decay in **Figure 2.** This model shows two important things about radioactive decay. First, the mass number is conserved. The sum of the mass numbers of the starting materials is always equal to the sum of the mass numbers of the products. Second, charge is conserved. The sum of the charges of the starting materials is always equal to the sum of the charges of the products.

✓ *Reading Check* **What two things are conserved in radioactive decay?** (*See the Appendix for answers to Reading Checks.*)

Figure 3 Beta Decay of Carbon-14



Beta Decay

The release of a beta particle from a nucleus is called *beta decay*. A *beta particle* can be an electron or a positron. An electron has a charge of 1−. A positron has a charge of 1+. But electrons and positrons have a mass of almost 0. The mass number of a beta particle is 0 because it has no protons or neutrons.

Two Types of Beta Decay

A carbon-14 nucleus undergoes beta decay, as shown in the model in **Figure 3.** During this kind of decay, a neutron breaks into a proton and an electron. Notice that the nucleus becomes a nucleus of a different element. And both mass number and charge are conserved.

Not all isotopes of an element decay in the same way. **Isotopes** are atoms that have the same number of protons as other atoms of the same element do but that have different numbers of neutrons. A carbon-11 nucleus undergoes beta decay when a proton breaks into a positron and a neutron. But during any beta decay, the nucleus changes into a nucleus of a different element. And both mass number and charge are conserved.

isotope an atom that has the same number of protons (or the same atomic number) as other atoms of the same element do but that has a different number of neutrons (and thus a different atomic mass)

Gamma Decay

Energy is also given off during alpha decay and beta decay. Some of this energy is in the form of light that has very high energy called *gamma rays*. The release of gamma rays from a nucleus is called *gamma decay*. This decay happens as the particles in the nucleus shift places. Gamma rays have no mass or charge. So, gamma decay alone does not cause one element to change into another element.

The Penetrating Power of Radiation

The three forms of nuclear radiation have different abilities to penetrate, or go through, matter. This difference is due to their mass and charge, as you can see in **Figure 4.**

Effects of Radiation on Matter

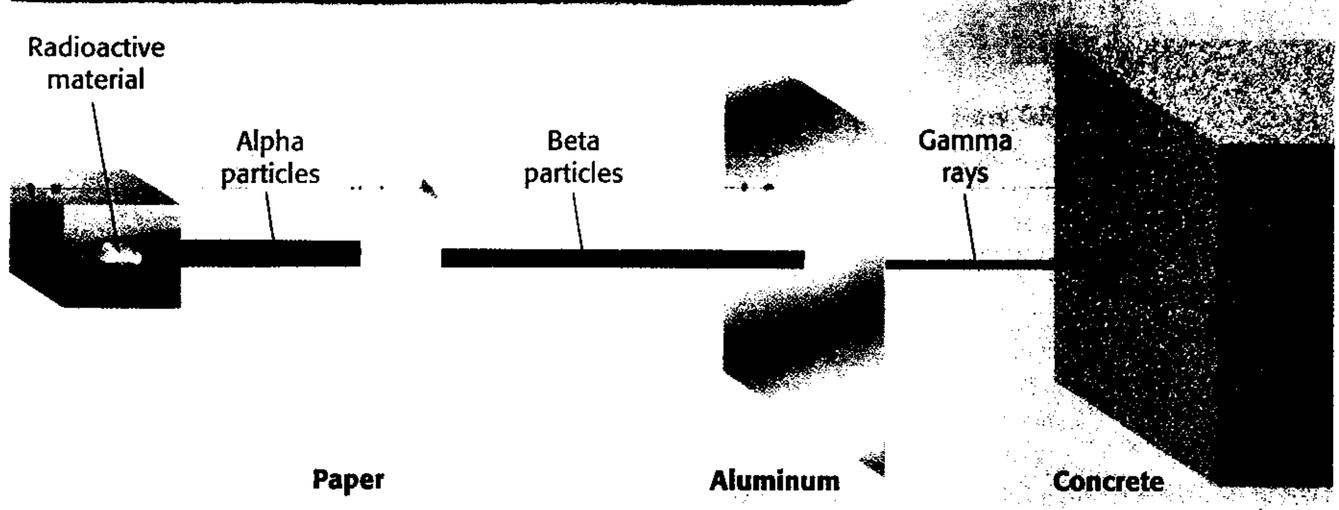
Atoms that are hit by nuclear radiation can give up electrons. Chemical bonds between atoms can break when hit by nuclear radiation. Both of these things can cause damage to living and nonliving matter.

Damage to Living Matter

When an organism absorbs radiation, its cells can be damaged. Radiation can cause burns like those caused by touching something that is hot. A single large exposure to radiation can lead to *radiation sickness*. Symptoms of this sickness include fatigue, loss of appetite, and hair loss. Destruction of blood cells and even death can result. Exposure to radiation can also increase the risk of cancer because of the damage done to cells. People who work near radioactive materials often wear a film badge. Radiation will make an image on the film to warn the person if the levels of radiation are too high.

Reading Check Name three symptoms of radiation sickness.

Figure 4 **The Penetrating Abilities of Nuclear Radiation**



▲ **Alpha particles** have a greater charge and mass than beta particles and gamma rays do. Alpha particles travel about 7 cm through air and are stopped by paper or clothing.

▲ **Beta particles** have a 1− or 1+ charge and almost no mass. They are more penetrating than alpha particles. Beta particles travel about 1 m through air but are stopped by 3 mm of aluminum.

▲ **Gamma rays** have no charge or mass and are the most penetrating. They are blocked by very dense, thick materials, such as a few centimeters of lead or a few meters of concrete.

CONNECTION TO

WRITING **Radon in the Home** Radioactive radon-222 forms from the radioactive decay of uranium found in soil and rocks. Because radon is a gas, it can enter buildings through gaps in the walls and floors. Research the hazards of radon. Identify methods used to detect it and to prevent exposure to it. Present your findings by writing a pamphlet in the form of a public service announcement.

Damage to Nonliving Matter

Radiation can also damage nonliving matter. When metal atoms lose electrons, the metal is weakened. For example, radiation can cause the metal structures of buildings, such as nuclear power plants, to become unsafe. High levels of radiation from the sun can damage spacecraft.

Damage at Different Depths

Gamma rays go through matter easily. They can cause damage deep within matter. Beta particles cause damage closer to the surface. Alpha particles cause damage very near the surface. But alpha particles are larger and more massive than the particles of other kinds of radiation. So, if a source of alpha particles enters an organism, the particles can cause the most damage.

Finding a Date by Decay

Finding a date for someone can be tough—especially if the person is several thousand years old! Hikers in the Italian Alps found the remains of the Iceman, shown in **Figure 5**, in 1991. Scientists were able to estimate the time of death—about 5,300 years ago! How did the scientists do this? The decay of radioactive carbon was the key.

Carbon-14—It's in You!

Carbon atoms are found in all living things. A small percentage of these atoms is radioactive carbon-14 atoms. During an organism's life, the percentage of carbon-14 in the organism stays about the same. Any atoms that decay are replaced. Plants take in carbon from the atmosphere. Animals take in carbon from food. But when an organism dies, the carbon-14 is no longer replaced. Over time, the level of carbon-14 in the remains of the organism drops because of radioactive decay.

Figure 5 *The remains of the Iceman, a 5,300-year-old mummy, are the best-preserved remains of a human from that time.*

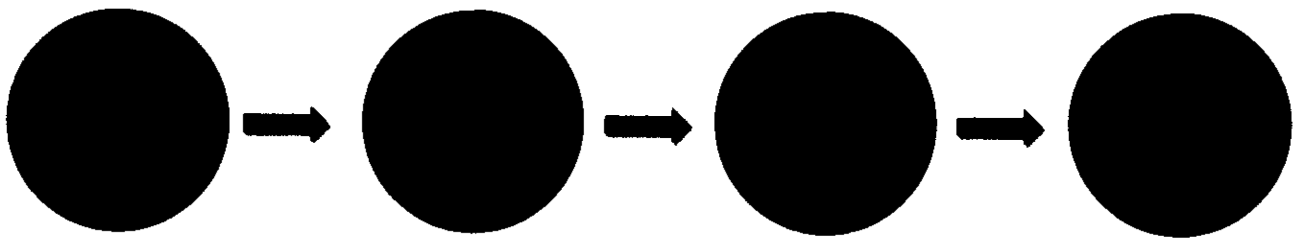
Figure 6 **Radioactive Decay and Half-Life**

The **original sample** contains a certain amount of radioactive isotope.

After **one half-life,** one-half of the original sample has decayed, and half is unchanged.

After **two half-lives,** one-fourth of the original sample remains unchanged.

After **three half-lives,** only one-eighth of the original sample remains unchanged.



A Steady Rate of Decay

Scientists have found that every 5,730 years, half of the carbon-14 in a sample decays. The rate of decay is constant. The rate is not changed by other conditions, such as temperature or pressure. Each radioactive isotope has its own rate of decay, called half-life. A **half-life** is the amount of time it takes one-half of the nuclei of a radioactive isotope to decay. **Figure 6** is a model of this process. **Table 1** lists some isotopes that have a wide range of half-lives.

half-life the time needed for half of a sample of a radioactive substance to undergo radioactive decay

✓ Reading Check What is the half-life of carbon-14?

Determining Age

Scientists measured the number of decays in the Iceman's body each minute. They found that a little less than half of the carbon-14 in the body had changed. In other words, not quite one half-life of carbon-14 (5,730 years) had passed since the Iceman died.

Carbon-14 can be used to find the age of objects up to 50,000 years old. To find the age of older things, other elements must be used. For example, potassium-40 has a half-life of 1.3 billion years. It is used to find the age of dinosaur fossils.

Table 1 **Examples of Half-Lives**

Isotope	Half-life	Isotope	Half-life
Uranium-238	4.5 billion years	Polonium-210	138 days
Oxygen-21	3.4 s	Nitrogen-13	10 min
Hydrogen-3	12.3 years	Calcium-36	0.1 s

MATH PRACTICE

How Old Is It?

One-fourth of the original carbon-14 of an antler is unchanged. As shown in **Figure 6,** two half-lives have passed. To determine the age of the antler, multiply the number of half-lives that have passed by the half-life of carbon-14. The antler's age is 2 times the half-life of carbon-14:

$$\text{age} = 2 \times 5{,}730 \text{ years}$$
$$\text{age} = 11{,}460 \text{ years}$$

Determine the age of a wooden spear that contains one-eighth of its original amount of carbon-14.

Uses of Radioactivity

You have learned how radioactive isotopes are used to determine the age of objects. But radioactivity is used in many areas for many things. The smoke detectors in your home might even use a small amount of radioactive material! Some isotopes can be used as tracers. *Tracers* are radioactive elements whose paths can be followed through a process or reaction.

Reading Check What is a tracer?

Radioactivity in Healthcare

Doctors use tracers to help diagnose medical problems. Radioactive tracers that have short half-lives are fed to or injected into a patient. Then, a detector is used to follow the tracer as it moves through the patient's body. The image in **Figure 7** shows an example of the results of a tracer study. Radioactive materials are also used to treat illnesses, including cancer. Radioactive materials can even help prevent illness. For example, many food and healthcare products are sterilized using radiation.

INTERNET ACTIVITY

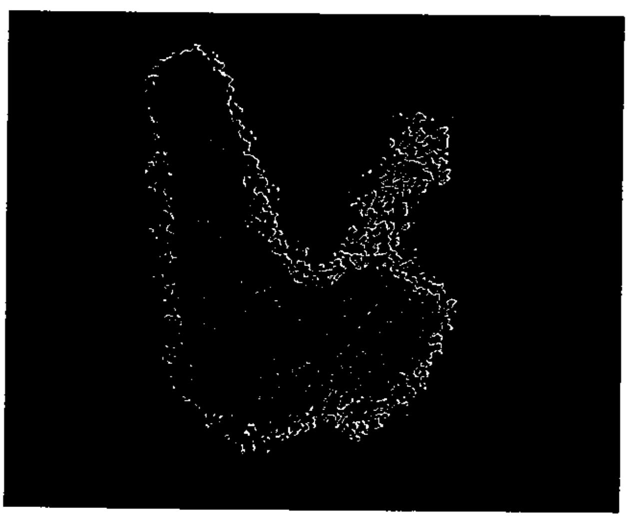
For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HP5RADW.**

Radioactivity in Industry

Radioactive isotopes can also help detect defects in structures. For example, radiation is used to test the thickness of metal sheets as they are made. Another way radioactive isotopes are used to test structures is shown in **Figure 7.**

Some space probes have been powered by radioactive materials. The energy given off as nuclei decay is converted into electrical energy for the probe.

Figure 7 Uses of Radioactivity in Healthcare and in Industry



Radioactive iodine-131 was used to make this scan of a thyroid gland. The dark area shows the location of a tumor.

Tracers are used to find weak spots in materials and leaks in pipes. A Geiger counter is often used to detect the tracer.

Review

Summary

- Henri Becquerel discovered radioactivity while trying to study X rays. Radioactivity is the process by which a nucleus gives off nuclear radiation.
- An alpha particle is composed of two protons and two neutrons. A beta particle can be an electron or a positron. Gamma rays are a form of light with very high energy.
- Gamma rays penetrate matter better than alpha or beta particles do. Beta particles penetrate matter better than alpha particles do.
- Nuclear radiation can damage living and nonliving matter.
- Half-life is the amount of time it takes for one-half of the nuclei of a radioactive isotope to decay. The age of some objects can be determined using half-lives.
- Uses of radioactive materials include detecting defects in materials, sterilizing products, diagnosing illness, and generating electrical energy.

Using Key Terms

1. Use the following terms in the same sentence: *mass number* and *isotope*.

Understanding Key Ideas

2. Which of the following statements correctly describes the changes that happen in radioactive decay?
   - **a.** Alpha decay changes the atomic number and the mass number of a nucleus.
   - **b.** Gamma decay changes the atomic number but not the mass number of a nucleus.
   - **c.** Gamma decay changes the mass number but not the atomic number of a nucleus.
   - **d.** Beta decay changes the mass number but not the atomic number of a nucleus.
3. Describe the experiment that led to the discovery of radioactivity.
4. Give two examples of how radioactivity is useful and two examples of how it is harmful.

Math Skills

5. A rock contains one-fourth of its original amount of potassium-40. The half-life of potassium-40 is 1.3 billion years. Calculate the rock's age.
6. How many half-lives have passed if a sample contains one-sixteenth of its original amount of radioactive material?

Critical Thinking

7. **Making Comparisons** Compare the penetrating power of the following nuclear radiation: alpha particles, beta particles, and gamma rays.
8. **Making Inferences** Why would uranium-238 not be useful in determining the age of a spear that is thought to be 5,000 years old? Explain your reasoning.

Interpreting Graphics

9. Look at the figure below. Which nucleus could not undergo alpha decay? Explain your answer.

Beryllium-10 **Hydrogen-3**

6 neutrons, 4 protons — 2 neutrons, 1 proton

2

Energy from the Nucleus

From an early age, you were probably told not to play with fire. But fire itself is neither good nor bad. It simply has benefits and hazards.

READING WARM-UP

Objectives

- Describe nuclear fission.
- Identify advantages and disadvantages of fission.
- Describe nuclear fusion.
- Identify advantages and disadvantages of fusion.

Terms to Learn

nuclear fission
nuclear chain reaction
nuclear fusion

READING STRATEGY

Reading Organizer As you read this section, make a table comparing nuclear fission and nuclear fusion.

Likewise, getting energy from the nucleus of an atom has benefits and hazards. In this section, you will learn about two ways to get energy from the nucleus—fission (FISH uhn) and fusion (FYOO zhuhn). Gaining an understanding of the advantages and disadvantages of fission and fusion is important for people who will make decisions about the use of this energy—people like you!

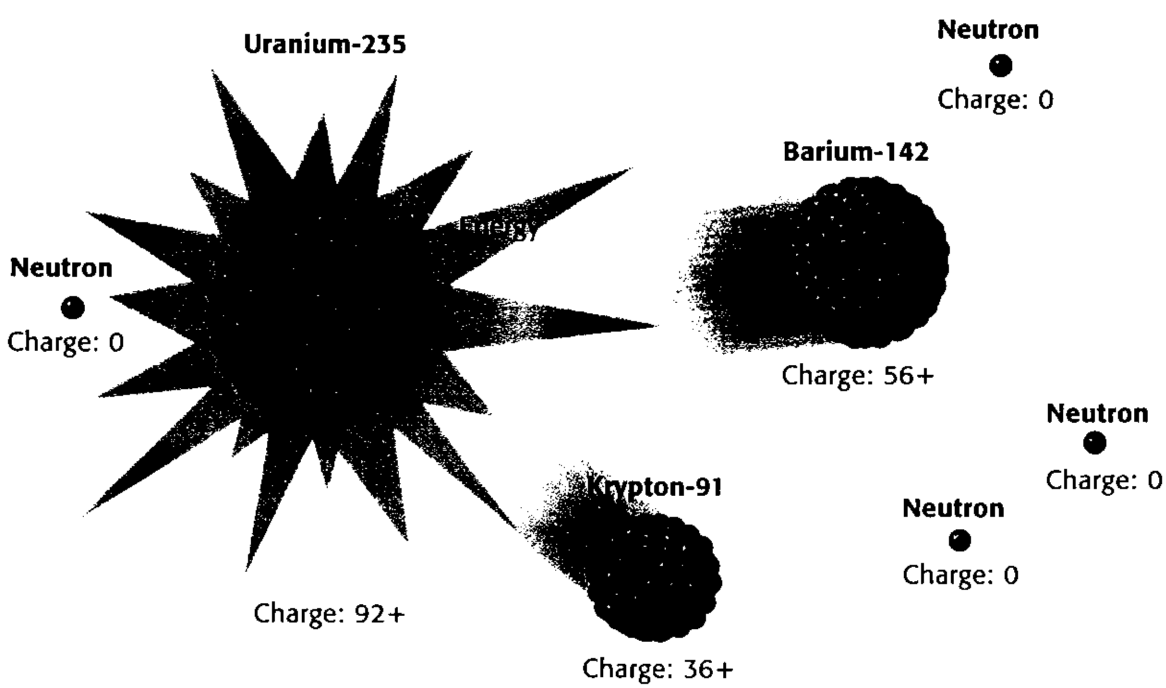
Nuclear Fission

The nuclei of some atoms decay by breaking into two smaller, more stable nuclei. **Nuclear fission** is the process by which a large nucleus splits into two small nuclei and releases energy.

The nuclei of some uranium atoms, as well as the nuclei of other large atoms, can undergo nuclear fission naturally. Large atoms can also be forced to undergo fission by hitting the atoms with neutrons, as shown by the model in **Figure 1.**

Reading Check What happens to a nucleus that undergoes nuclear fission? (*See the Appendix for answers to Reading Checks.*)

Figure 1 **Fission of a Uranium-235 Nucleus**



Energy from Matter

Did you know that matter can be changed into energy? It's true! If you could find the total mass of the products in **Figure 1** and compare it with the total mass of the reactants, you would find something strange. The total mass of the products is slightly less than the total mass of the reactants. Why are the masses different? Some of the matter was converted into energy.

The amount of energy given off when a single uranium nucleus splits is very small. But this energy comes from a very small amount of matter. The amount of matter converted into energy is only about one-fifth the mass of a hydrogen atom. And hydrogen is the smallest atom that exists! Look at **Figure 2.** The nuclear fission of the uranium nuclei in one fuel pellet releases as much energy as the chemical change of burning about 1,000 kg of coal.

Figure 2 *Each of these small fuel pellets can generate a large amount of energy through the process of nuclear fission.*

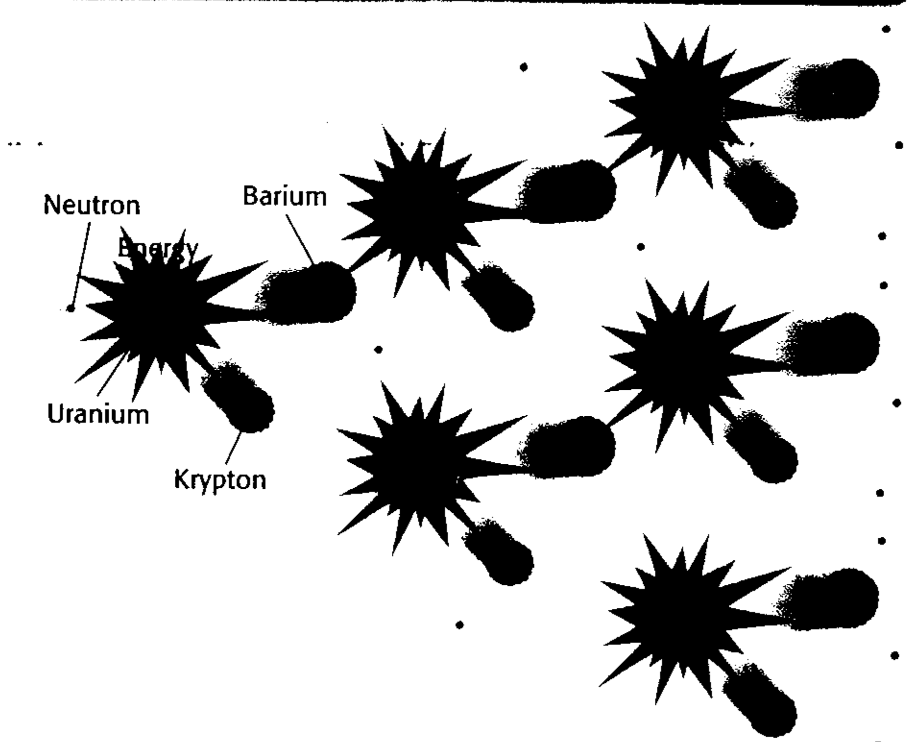
Nuclear Chain Reactions

Look at **Figure 1** again. Suppose that two or three of the neutrons produced split other uranium-235 nuclei. So, energy and more neutrons are given off. And then suppose that two or three of the neutrons that were given off split other nuclei and so on. This example is one type of **nuclear chain reaction,** a continuous series of nuclear fission reactions. A model of an uncontrolled chain reaction is shown in **Figure 3.**

nuclear fission the splitting of the nucleus of a large atom into two or more fragments; releases additional neutrons and energy

nuclear chain reaction a continuous series of nuclear fission reactions

Figure 3 **An Uncontrolled Nuclear Chain Reaction**



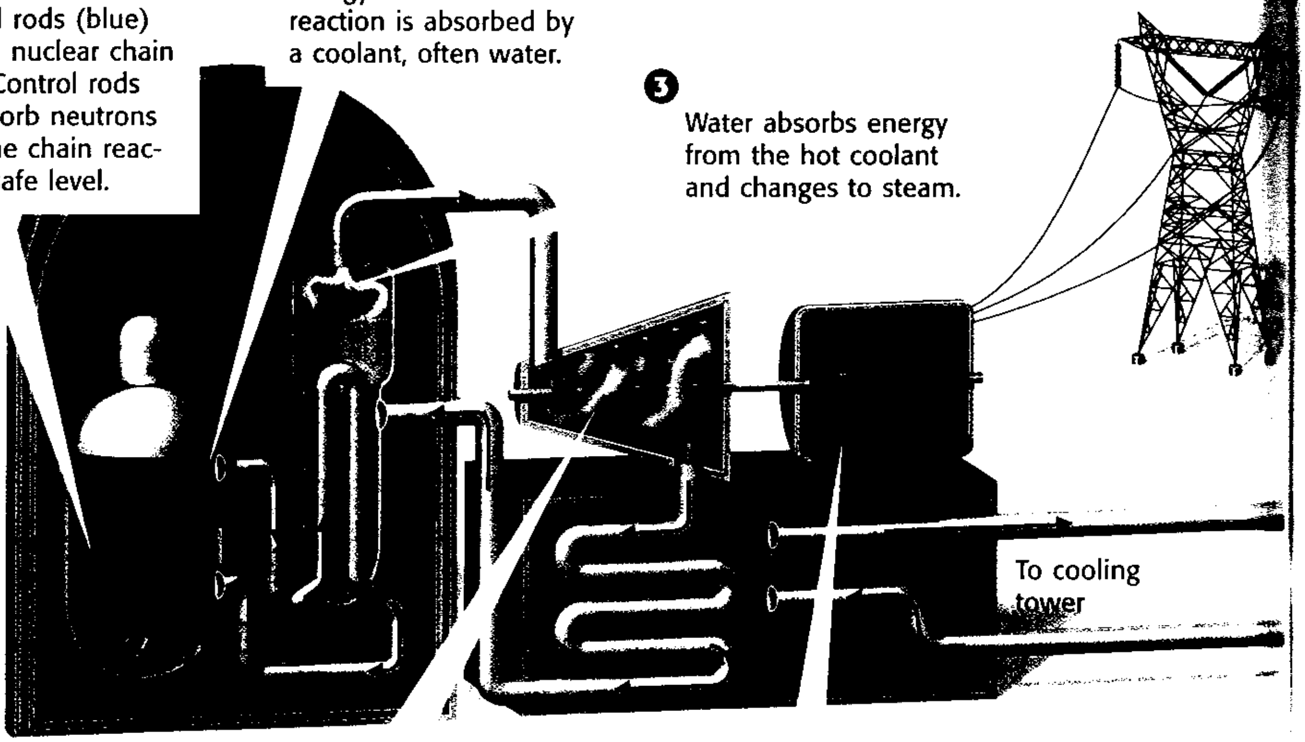
Energy from a Chain Reaction

In an *uncontrolled chain reaction,* huge amounts of energy are given off very quickly. For example, the tremendous energy of an atomic bomb is the result of an uncontrolled chain reaction. On the other hand, nuclear power plants use *controlled chain reactions.* The energy released from the nuclei in the uranium fuel within the nuclear power plants is used to generate electrical energy. **Figure 4** shows how a nuclear power plant works.

Advantages and Disadvantages of Fission

Every form of energy has advantages and disadvantages. To make informed decisions about energy use, you need to know both sides. For example, burning wood to keep warm on a cold night could save your life. But a spark from the fire could start a forest fire. Nuclear fission has advantages and disadvantages that you should think about.

Figure 4 How a Nuclear Power Plant Works



Accidents

A concern that many people have about nuclear power is the risk of an accident. In Chernobyl, Ukraine, on April 26, 1986, an accident happened, as shown in **Figure 5.** An explosion put large amounts of radioactive uranium fuel and waste products into the atmosphere. The cloud of radioactive material spread over most of Europe and Asia. It reached as far as North America.

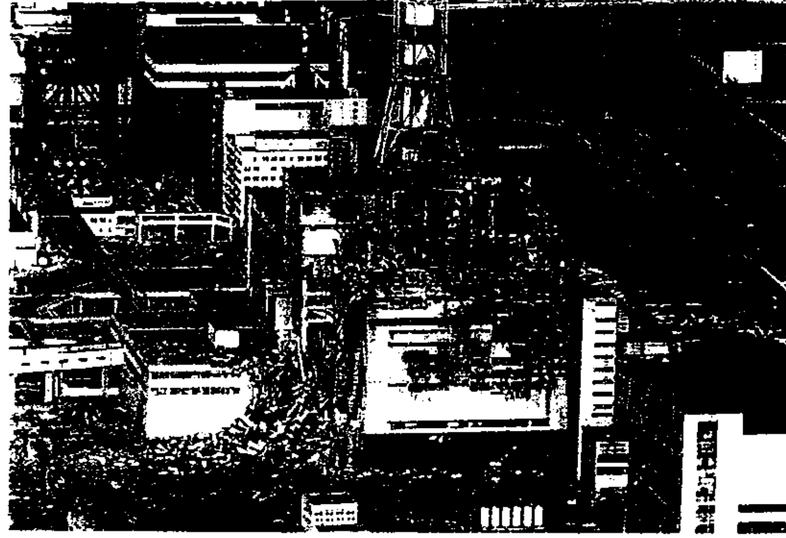


Figure 5 *During a test at the Chernobyl nuclear power plant, the emergency protection system was turned off. The reactor overheated, which resulted in an explosion.*

What Waste!

Another concern about nuclear power is nuclear waste. This waste includes used fuel rods, chemicals used to process uranium, and even shoe covers and overalls worn by workers. Controlled fission has been carried out for only about 50 years. But the waste will give off high levels of radiation for thousands of years. The rate of radioactive decay cannot be changed. So, the nuclear waste must be stored until it becomes less radioactive. Most of the used fuel rods are stored in huge pools of water. Some of the liquid wastes are stored in underground tanks. However, scientists continue to look for better ideas for long-term storage of nuclear waste.

Nuclear Versus Fossil Fuel

Nuclear power plants cost more to build than power plants that use fossil fuels. But nuclear power plants often cost less to run than plants that use fossil fuels because less fuel is needed. Also, nuclear power plants do not release gases, such as carbon dioxide, into the atmosphere. The use of fission allows our supply of fossil fuels to last longer. However, the supply of uranium is limited.

Reading Check **What are two advantages of using nuclear fission to generate electrical energy?**

CONNECTION TO

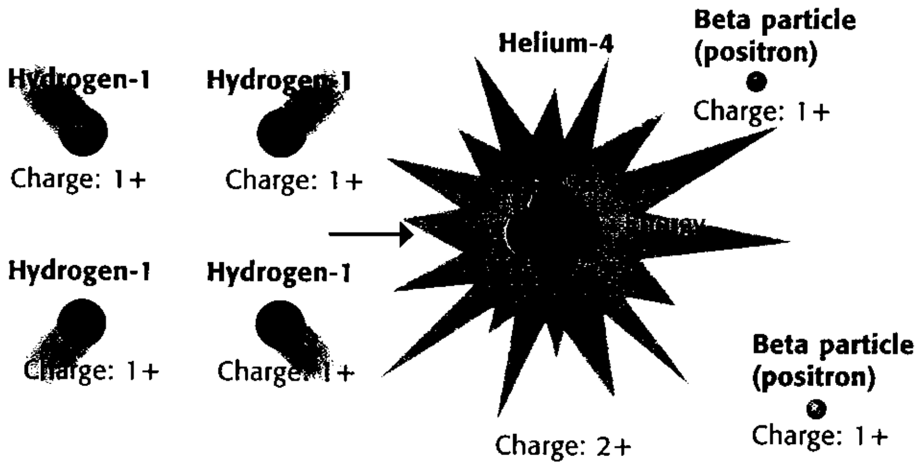
WRITING **Storage Site** The government of the United States is required by law to build underground storage for nuclear waste. The waste must be stored for a very long time and cannot escape into the environment. In your **science journal,** write a one-page paper describing the characteristics of a good location for these underground storage sites.

QUICK LAB

Gone Fission

1. Make two paper balls from a **sheet of paper.**
2. Stand in a group with your classmates. Make sure you are an arm's length from your other classmates.
3. Your teacher will gently toss a paper ball at the group. If you are touched by a ball, gently toss your paper balls at the group.
4. Explain how this activity is a model of a chain reaction. Be sure to explain what the students and the paper balls represent.

Figure 6 **Nuclear Fusion of Hydrogen**



Nuclear Fusion

nuclear fusion the combination of the nuclei of small atoms to form a larger nucleus; releases energy

Fusion is another nuclear reaction in which matter is converted into energy. In **nuclear fusion,** two or more nuclei that have small masses combine, or fuse, to form a larger nucleus.

Plasma Needed

In order for fusion to happen, the repulsion between positively charged nuclei must be overcome. Very high temperatures are needed—more than 100,000,000°C! At these high temperatures, matter is a plasma. *Plasma* is the state of matter in which electrons have been removed from atoms. So, plasma is made up of ions and electrons. One place that has such temperatures is the sun. In the sun's core, hydrogen nuclei fuse to form a helium nucleus, as shown in the model in **Figure 6.**

Reading Check Describe the process of nuclear fusion.

CONNECTION TO

Elements of the Stars
Hydrogen is not the only fuel that stars use for fusion. Research other elements that stars can use as fuels and the fusion reactions that make these elements. Make a poster showing what you learn.

Advantages and Disadvantages of Fusion

Energy for your home cannot yet be generated using nuclear fusion. First, very high temperatures are needed. Second, more energy is needed to make and hold the plasma than is generated by fusion. But scientists predict that fusion will provide electrical energy in the future—maybe in your lifetime!

Less Accident Prone

The concern about an accident such as the one at Chernobyl is much lower for fusion reactors. If a fusion reactor exploded, very little radioactive material would be released. Fusion products are not radioactive. And the hydrogen-3 used for fuel in experimental fusion reactors is much less radioactive than the uranium used in fission reactors.

Oceans of Fuel

Scientists studying fusion use hydrogen-2 and hydrogen-3 in their work. Hydrogen-1 is much more common than these isotopes. But there is enough of them in Earth's waters to provide fuel for millions of years. Also, a fusion reaction releases more energy per gram of fuel than a fission reaction does. So, fusion saves more resources than fission does, as shown in **Figure 7.**

Less Waste

The products of fusion reactions are not radioactive. So, fusion is a "cleaner" source of energy than fission is. There would be much less radioactive waste. But to have the benefits of fusion, scientists need money to pay for research.

Figure 7 *Fusing the hydrogen-2 in 3.8 L of water would release about the same amount of energy as burning 1,140 L of gasoline!*

SECTION Review

Summary

- In nuclear fission, a massive nucleus breaks into two nuclei.
- In nuclear fusion, two or more nuclei combine to form a larger nucleus.
- Nuclear fission is used in power plants to generate electrical energy. A limited fuel supply and radioactive waste products are disadvantages of fission.
- Nuclear fusion cannot yet be used as an energy source, but plentiful fuel and little waste are advantages of fusion.

Using Key Terms

Complete each of the following sentences by choosing the correct term from the word bank.

nuclear fission
nuclear fusion
nuclear chain reaction

1. During ___, small nuclei combine.
2. During ___, nuclei split one after another.

Understanding Key Ideas

3. Which of the following is an advantage nuclear fission has over fossil fuels?
   a. unlimited supply of fuel
   b. less radioactive waste
   c. fewer building expenses
   d. less released carbon dioxide
4. Which kind of nuclear reaction is currently used to generate electrical energy?
5. Which kind of nuclear reaction is the source of the sun's energy?
6. What particle is needed to begin a nuclear chain reaction?
7. In both fission and fusion, what is converted into energy?

Math Skills

8. Imagine that a uranium nucleus splits and releases three neutrons and that each neutron splits another nucleus. If the first split occurs in stage 1, how many nuclei will split during stage 4?

Critical Thinking

9. **Making Comparisons** Compare nuclear fission with nuclear fusion.
10. **Analyzing Processes** The floor of a room is covered in mousetraps that each hold two table-tennis balls. One ball is dropped onto a trap. The trap snaps shut, and the balls on it fly into the air and fall on other traps. What nuclear process is modeled here? Explain your answer.

Model-Making Lab

Domino Chain Reactions

OBJECTIVES

Build models to represent controlled and uncontrolled nuclear chain reactions.

Compare models of controlled and uncontrolled nuclear chain reactions.

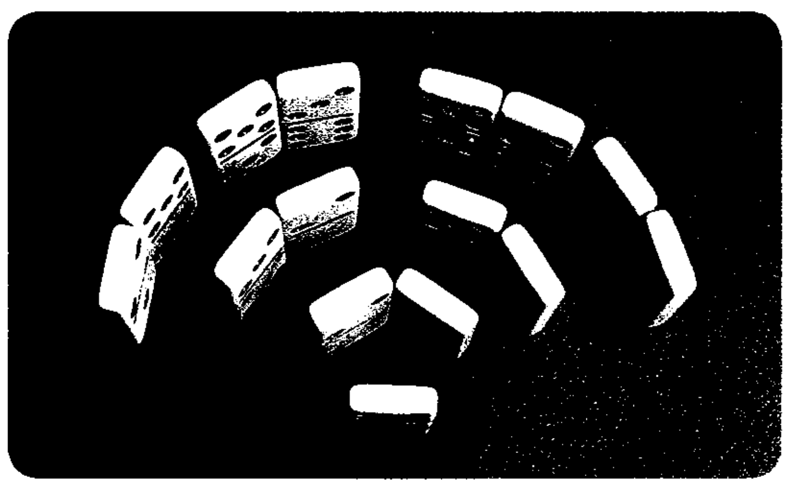
MATERIALS

- dominoes (15)
- stopwatch

Fission of uranium-235 is a process that relies on neutrons. When a uranium-235 nucleus splits into two smaller nuclei, it releases two or three neutrons that can cause neighboring nuclei to undergo fission. This fission can result in a nuclear chain reaction. In this lab, you will build two models of nuclear chain reactions, using dominoes.

Procedure

1. For the first model, set up the dominoes as shown below. When pushed over, each domino should hit two dominoes in the next row.



2. Measure the time it takes for all the dominoes to fall. To do this, start the stopwatch as you tip over the front domino. Stop the stopwatch when the last domino falls. Record this time.
3. If some of the dominoes do not fall, repeat steps 1 and 2. You may have to adjust the setup a few times.
4. For the second model, set up the dominoes as shown at left. The domino in the first row should hit both of the dominoes in the second row. Beginning with the second row, only one domino from each row should hit both of the dominoes in the next row.
5. Repeat step 2. Again, you may have to adjust the setup a few times to get all the dominoes to fall.

Analyze the Results

1. **Classifying** Which model represents an uncontrolled chain reaction? Which represents a controlled chain reaction? Explain your answers.

2. **Analyzing Results** Imagine that each domino releases a certain amount of energy as it falls. Compare the total amount of energy released in the two models.

3. **Analyzing Data** Compare the time needed to release the energy in the models. Which model took longer to release its energy?

Draw Conclusions

4. **Evaluating Models** In a nuclear power plant, a chain reaction is controlled by using a material that absorbs neutrons. Only enough neutrons to continue the chain reaction are allowed to continue splitting uranium-235 nuclei. Explain how your model of a controlled nuclear chain reaction modeled this process.

5. **Applying Conclusions** Why must uranium nuclei be close to each other in order for a nuclear chain reaction to happen? (Hint: What would happen in your model if the dominoes were too far apart?)